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LABORATORY EVALUATION OF COMMERCIAL ENGINE OIL QUALITY

INTERIM REPORT
BFLRF No. 228

By

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Defense General Supply Center was considering initiating a Paperless Ordering Procurement System (POPS) for commercial off-the-shelf engine oils for administrative service. Currently, administrative engine oils (MIL-L-46152) of assured quality are procured under an oil qualification process that generates a list of approved products (Qualified Products List). There is currently no formal qualification procedure for commercial gasoline engine oils. During 1979-80, the Army surveyed commercial engine oil quality and found several instances where commercial rebranded products had questionable quality relative to their stated quality level. The objective of the current project was to determine the quality of commercial oils in the marketplace and determine if the overall quality was sufficient to allow a POPS-type system. To make this determination, 41 commercial engine oils were purchased in the Washington, DC and San Antonio, Texas areas and then analyzed using standard test procedures to determine oil quality versus the physical/chemical requirements of MIL-L-46152. The program results show that 57.5

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percent of the samples failed one or more of the physical/chemical requirements of MIL-L-46152. Although 17.5 percent of the failures were considered borderline, 40 percent of the samples clearly failed at least one test. Foam test and low-temperature viscosity were the requirements most frequently failed. Thus, based on the percentage of samples that failed property tests, it is not advisable for the U.S. Army to procure commercially available rebranded oils for administrative service.

EXECUTIVE SUMMARY

Problems and Objectives: Defense General Supply Center was considering initiating a Paperless Ordering Procurement System (POPS) for commercial off-the-shelf engine oils for administrative service. Currently, administrative engine oils (MIL-L-46152) of assured quality are procured under an oil qualification process that generates a list of approved products (Qualified Products List). There is currently no formal qualification procedure for commercial gasoline engine oils. During 1979-80, the Army surveyed commercial engine oil quality and found several instances where commercial rebranded products had questionable quality relative to their stated quality level. The objective of the current project was to determine the quality of commercial oils in the marketplace and determine if the overall quality was sufficient to allow a POPS-type system.

Importance of Project: This project will determine if commercial oil quality is consistent enough to allow the adoption of a POPS-type procurement system for engine oil intended for use in the Government administrative vehicle fleet.

Technical Approach: A total of 41 commercial engine oils were purchased in the Washington, DC and San Antonio, Texas areas and then analyzed using standard test procedures to determine oil quality versus the physical/chemical requirements of MIL-L-46152.

Accomplishments: The program has been completed. Overall, 57.5 percent of the samples failed one or more of the physical/chemical tests of MIL-L-46152. Although 17.5 percent of the failures were considered borderline, 40 percent of the samples clearly failed at least one test. Foam test and low-temperature viscosity were the requirements most frequently failed.

Military Impact: Based on the percentage of samples that failed property tests, it is not advisable for the U.S. Army to procure commercially available rebranded oils for administrative service. Use of low-quality engine oil could result in engine damage and increased maintenance costs and engine warranty invalidation.

FOREWORD

This work was performed at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, under Contract Nos. DAAK70-85-C-0007 and DAAK70-87-C-0043, for the period November 1986 through April 1988. Work was funded by the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center), Ft. Belvoir, Virginia. Mr. T.C. Bowen, Belvoir RDE Center (STRBE-VF), served as the contracting officer's representative and technical monitor.

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I. INTRODUCTION/BACKGROUND

At the time of this work, the engine oil specification for Department of Defense (DOD) administrative vehicles was MIL-L-46152B.(1)* This specification assures the quality of engine oils used in both spark ignition and moderate-duty compression ignition administrative vehicles by requiring physical, chemical, and engine tests of the lubricant. Lubricants test data are presented to the Lubricant Review Institute (LRI) (2), and oils that pass the requirements are put on a qualified product list (QPL) and may then be sold to DOD on a bid basis. Although this system assures the quality of lubricants purchased by the DOD, it has had difficulty in supplying these lubricants in conveniently small quantities (e.g., quart cans) that are desirable for smaller motor pools and remote locations. Because of this practice and for reasons of economy, there is a great deal of interest in the use of commercially available engine oils in DOD motor vehicles. In 1979 the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), currently the Belvoir Research, Development and Engineering Center, evaluated the quality of commercial automotive engine oils in an effort to see if they could meet the requirements of MIL-L-46152.(3) The conclusions of this effort were that 11 of the 17 samples tested failed to meet MIL-L-46152 requirements and that 6 of the samples appeared to be formulated with insufficient additives. These results effectively eliminated the possibility of using commercial engine oils in DOD vehicles since the benefits of using these oils (economy and convenience) could be more than offset by the potential for increased maintenance and warranty issues. The purpose of this current effort is to reevaluate the quality of commercially available engine oils to determine if oil quality has improved since the 1979 evaluation.

II. METHOD OF APPROACH

Commercially available rebranded lubricants were purchased in local stores. Rebranded lubricants were selected rather than name brand, since the rebranded lubricants represent the lower cost lubricants that a military supply system would be likely to procure under recent competitive bid regulations. Additionally, the rebranded lubricants may be representative of the lower quality commercially available lubricants. Any DOD

*Underscored numbers in parentheses refer to the list of references at the end of this report.

procurement program should therefore expect to obtain lubricants of this quality or better if name brand lubricants were purchased. Selection of the rebranded lubricants should represent a worst-case analysis of lubricants that could potentially be used in DOD vehicles. Oil viscosity grades SAE-30, 5W-20, 10W-30, and 15W-40 were specified by MIL-L-46152B. The U.S. Army Belvoir Research, Development and Engineering Center sampling concentrated in obtaining 10W-30 products, while the BFLRF sampling obtained a mix of viscosity grades. With one exception, lubricants advertised to meet SF/CC or SF/CD quality levels were procured since most vehicle warranties mandate this quality lubricant. Belvoir RDE Center purchased 21 oils in the Baltimore, MD and northern Virginia areas, and Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute purchased 20 lubricants in the San Antonio, TX area. The wide geographic separation of the two sampling locations minimized the possibility of duplicate products being procured under different labels and provided a better sampling of nationwide oil quality. Both sampling agencies purchased 2 quarts of each oil at local stores. Each sample was assigned a code number and the following information recorded:

Code Number
Brand Name
Manufacturer
Viscosity Grade
Advertised Quality Level (API service class)
Place Purchased

TABLE 1 lists the laboratory tests performed on each sample, while TABLE 2 gives a breakdown of viscosity grade of the lubricant samples by geographic locations.

Attempts were made to obtain more multiviscosity lubricants in the San Antonio area, but the samples were not available off-the-shelf. TABLE 3 contains a cross tabulation of viscosity grade and API Service Classification for samples in the data base. Twenty-four 10W-30, nine SAE grade 30, and one 5W-30 grade were labeled as SF/CC. Four oils were labeled SF/CD (one 10W-30, two SAE 30, one 15W-40), while there was one oil labeled SF only (10W-30). One oil labeled for API Service Classification SA (SAE 30 grade) was included for information only. TABLE 4 presents a breakdown of the source of samples in this survey. Most of the samples were obtained from supermarkets, discount/department stores, and auto parts stores, with only five samples being obtained from service stations.

TABLE 1. List of Laboratory Tests Performed on Each Lubricant

Title	Method
Flash Point, °C	D 92
Pour Point, °C	D 97
Copper Corrosion, 3 hr @ 100°C	D 130
Kinematic Viscosity @ 40°C, cSt	D 445
Kinematic Viscosity @ 100°C, cSt	D 445
Viscosity Index	D 2270
Apparent Viscosity by CCS, cP @ °C	D 2602
Borderline Pumping Temperature, °C	D 3829
Total Base Number	D 2896
Sulfated Ash, wt%	D 874
Ramsbottom Carbon Residue, wt%	D 524
Foaming Characteristics	D 892
Water by Karl Fischer, ppm	D 1744
TFOUT, minutes	D 4742
Sulfur, wt%	D 2622
Nitrogen, ppm	CLM
Barium, ppm	ICP
Boron, ppm	ICP
Magnesium, ppm	ICP
Manganese, ppm	ICP
Molybdenum, ppm	ICP
Nickel, ppm	ICP
Phosphorous, ppm	ICP
Sodium, ppm	ICP
Zinc, ppm	ICP
Barium, %	XRF
Calcium, ppm	XRF
Copper, ppm	XRF
Phosphorous, %	XRF
Sulfur, %	XRF
Zinc, %	XRF

TABLE 2. Viscosity Grades of Samples by Location

Viscosity Grade	San Antonio	Virginia/ Maryland
5W-20	0	0
5W-30	1	0
10W-30	7	20
15W-40	1	0
SAE 30	11	1
No. of Samples	20	21

TABLE 3. Viscosity Grade and API Service Classification of Samples

API Class	Viscosity Grade			
	10W-30	SAE 30	5W-30	15W-40
SF/CC	25	9	1	0
SF/CD	1	2	0	1
SF	1	0	0	0
SA	0	1	0	0

TABLE 4. Source of Samples

Source	No. of Samples
Department/Discount Store	10
Supermarket/Drug Store/ Hardware	13
Auto Parts Store	13
Service Station	5

III. DISCUSSION OF RESULTS

For discussion purposes, the oils have been grouped by API service classification and SAE viscosity grade. TABLE 5 shows the results of the individual lubricant analyses of the oils labeled as 10W-30 grade and SF/CC. The analyses of the 30 grade, SF/CC oils are presented in TABLE 6, while TABLE 7 contains the analyses of miscellaneous SF oils and the SA oil. TABLE 8 contains a summary of the properties of the 10W-30 SF/CC oils. Minimum, maximum, and average values and standard deviations are shown. TABLE 9 contains the same type of summarized property information for the single grade oils (SF/CC, SAE 30 grade). The average SAE 30 grade oil had a slightly higher viscosity at 100°C, and higher TBN than the average 10W-30 oil. The properties of the miscellaneous SF oils were not summarized because of the diversity of products in this category. TABLE 10 shows a distribution of the additive package chemistry types of oils in the data base. With the exception of the service classification SA oil, all the formulated oils contained zinc and phosphorous as expected. Eleven different additive package chemistry types were represented, with seven of the types present in only a single oil brand within the data base. Most of the oils had one of two different additive package types as 14 (35 percent) of the oils contained an additive package with magnesium, calcium, and sodium, while 13 (29 percent) of the oils had a magnesium-, copper-, and boron-based package.

Frequency distributions were conducted for selected oil properties. Figures 1 through 11 show oil property frequency distributions for the 10W-30 oils labeled SF/CC. The properties of a "composite" 10W-30 oil were derived by compiling the most frequently occurring property ranges as shown below:

Property	Range
Kinematic Viscosity, 100°C, cSt	10.0-10.5
Viscosity Index	130-135
Sulfated Ash, wt%	0.75-0.80
Flash Point, °C	205-210
Total Base No. (D 2896)	5-6
Zinc, ppm	900-1000
Phosphorous, ppm	800-900
Sulfur, wt%	0.45-0.50
Nitrogen, wt%	0.035-0.040 and 0.045-0.050
TFOUT, minutes	100-120 and 120-140

TABLE 5. Lubricant Analyses, 10W-30, SF/CC Oils

AL Number	15712	15807	15714	15715	15716	15717	15718	15719	15720	15721
Viscosity Grade	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30
Service Classification	SF/SE/CC	SF/SE/CC	SF/CC	SF/SE/CC	SF/SE/CC	SF/SE/CC	SF/CC	SF/SE/CC	SF/SE/CC	SF/SE/CC
Kinematic Viscosity, cSt										
at 100°C	11.21	10.23	11.24	9.58	10.23	10.2	11.09	10.74	10.91	10.66
at 40°C	78.46	68.48	76.24	67.38	72.1	63.22	75.08	63.54	76.81	63.94
Viscosity Index	133	134	138	122	126	148	137	160	130	157
Apparent Viscosity, cP										
at -20°C	3200	3200	3300	3400	3750	3150	3100	2750	3750	2975
Borderline Pumping										
Temperature, °C	-28.4	-30.6	-29.8	-31.3	-28.8	-32.4	-29.4	-35.3	-29.7	-34.2
Flash Point, °C	215	210	210	227	213	235	213	213	210	227
Pour Point, °C	-34.4	-34	-34.4	-34.4	-34.4	-34.4	-34.4	-37.1	-34.4	-34.4
Total Base Number, D 2896	5.4	6.4	5.5	4.8	5.4	4.9	4.4	5.2	4	5.6
Sulfated Ash, wt%	0.84	0.8	0.79	0.78	0.72	0.74	0.75	0.69	0.86	0.65
Carbon Residue, wt%	0.81	0.9	0.78	0.85	0.74	0.74	0.077	0.8	0.89	0.7
Elemental Content, wt%										
Sulfur	0.30	0.66	0.46	0.40	0.37	0.62	0.31	0.25	0.43	0.47
Nitrogen	0.04	0.04	0.05	0.044	0.047	0.038	0.049	0.036	0.055	0.042
Calcium	<0.01	0.06	<0.01	0.16	<0.01	<0.01	<0.01	0.05	<0.01	<0.01
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.10	0.10	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.09
Phosphorous	0.09	0.13	0.11	0.11	0.11	0.12	0.10	0.10	0.11	0.08
Elemental Content, wt%										
Copper	90	<10	91	81	92	10	85	<10	90	80
Boron	109	<1	106	<1	99	51	101	<1	123	113
Zinc	929	1000	803	943	827	1076	838	983	933	890
Phosphorous	849	895	798	885	805	954	815	884	910	818
Barium	<1	<1	<1	<1	<1	<1	5	<1	<1	2
Magnesium	954	356	841	1	799	980	810	346	910	928
Sodium	6	484	2	14	4	15	3	610	7	8
Foam/Foam-Stability, mL										
Sequence I	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	10/0
Sequence II	15/0	190/0	30/0	0/0	180/0	110/0	0/0	130/0	140/0	150/0
Sequence III	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	50/0	0/0
Copper Corrosion										
3 hr, @ 100°C	ND	3A	ND	ND	ND	ND	ND	ND	ND	ND
Water by Karl Fischer, wt%	0.06	0.172	0.19	0.18	0.22	0.19	0.07	0.17	0.28	0.14
TFOUT, Ox Induction, min	92	150	103	146	123	190	121	122	136	120

ND = Not determined.

TABLE 5. Lubricant Analyses, 10W-30, SF/CC Oils (Cont'd)

AL Number	15722	15723	15724	15725	15726	15727	15728	15729	15797	15771
Viscosity Grade	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30	10W-30
Service Classification	SF/SE/CC	SF/SE/CC	SF/CC	SF/CC	SF/CC	SF/CC	SF/SE/CC	SF/SE/CC	SF/SE/CC	SF/SE/CC
Kinematic Viscosity, cSt										
at 100°C	11.3	10.17	10.92	11.92	10.89	9.8	10.49	10.35	10.33	10.07
at 40°C	74.03	68.94	92.88	73.03	75.76	68.24	71.91	74.51	69.4	67.58
Viscosity Index	144	132	139	159	132	125	132	123	134	133
Apparent Viscosity, cP at -20°C	3200	2800	2850	3200	3650	3950	3150	3400	3325	3200
Borderline Pumping Temperature, °C	-30.6	-32.9	-30.2	-32.4	-30.2	-29.9	-29.5	-31.8	-29.4	-30
Flash Point, °C	204	218	210	229	232	207	221	235	205	207
Pour Point, °C	-34.4	-34.4	-37.1	-34.4	-34.4	-34.4	-37.1	-37.1	-30	-37.1
Total Base Number, D 2896	6.2	6	0.8	6.6	5.2	5.3	6.9	5.7	6	6.1
Sulfated Ash, wt%	0.83	0.87	0.77	1.04	0.86	0.67	0.94	0.77	0.77	0.91
Carbon Residue, wt%	0.87	1.03	0.81	1.08	0.78	0.73	0.89	0.88	0.82	0.81
Elemental Content, wt%										
Sulfur	0.47	0.78	0.26	0.44	0.47	0.36	0.25	0.86	0.50	0.25
Nitrogen	0.047	0.04	0.047	0.022	0.048	0.04	0.046	0.038	0.041	0.05
Calcium	0.06	0.07	<0.01	0.20	<0.01	0.01	0.08	0.05	0.05	<0.01
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01
Zinc	0.10	0.14	0.10	0.13	0.10	0.09	0.11	0.09	0.10	0.11
Phosphorous	0.10	0.14	0.09	0.14	0.10	0.09	0.10	0.10	0.10	0.10
Elemental Content, ppm										
Copper	<10	<10	98	<10	67	40	<10	<10	<10	98
Boron	76	<1	93	1	128	59	3	<1	<1	108
Zinc	1092	1444	799	1411	985	757	1062	982	946	864
Phosphorous	1015	1323	760	1282	920	736	989	909	871	866
Barium	<1	<1	1	<1	<1	464	7	2	2	<1
Magnesium	761	376	792	9	1031	548	367	360	318	837
Sodium	8	680		16	6	169	523	760	460	2
Foam/Foam-Stability, mL										
Sequence I	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Sequence II	0/0	40/0	190/0	320/0	290/0	285/0	160/0	130/0	160/0	220/0
Sequence III	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Copper Corrosion 3 hr, @ 100°C	ND	ND	ND	ND	ND	ND	ND	ND	1A	ND
Water by Karl Fischer, wt%	0.2	0.18	0.21	0.24	0.11	0.26	0.08	0.25	0.134	0.13
TFOUT, Ox Induction, min	175	254	120	182	120	102	167	147	154	129

TABLE 5. Lubricant Analyses, 10W-30, SF/CC Oils (Cont'd)

AL Number	15772	15786	15793	15790	15791
Viscosity Grade	10W-30	10W-30	10W-30	10W-30	10W-30
Service Classification	SF/SE/CC	SF/SE/CC	SF/CC	SF/SE/CC	SF/SE/CC
Kinematic Viscosity, cSt					
at 100°C	10.5	10.13	10.45	10.08	10.29
at 40°C	72.69	68.8	70.1	66.17	61.32
Viscosity Index	131	132	135	137	156
Apparent Viscosity, cP					
at -20°C	3700	3300	3650	2950	3050
Borderline Pumping					
Temperature, °C	-26.5	-29.7	-29.8	-33	-32.5
Flash Point, °C	224	216	215	204	216
Pour Point, °C	-34.4	-28	-34	-37	-37
Total Base Number, D 2896	5.6	6.6	6.1	6.3	6.1
Sulfated Ash, %	0.85	0.6	0.81	0.89	0.65
Carbon Residue, wt%	0.77	0.84	0.84	1.06	0.82
Elemental Content, wt%					
Sulfur	0.58	0.31	0.39	0.60	0.77
Nitrogen	0.046	0.052	0.038	0.043	0.038
Calcium	<0.01	<0.01	0.05	0.07	<0.01
Barium	0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.09	0.10	0.10	0.13	0.10
Phosphorous	0.10	0.09	0.08	0.15	0.11
Elemental Content, ppm					
Copper	59	62	<10	<10	<10
Boron	90	116	<1	1	58
Zinc	793	907	958	1459	1147
Phosphorous	756	783	876	1257	970
Barium	<1	1	<1	3	<1
Magnesium	807	958	332	354	1015
Sodium	1	0	509	750	5
Foam/Foam-Stability, mL					
Sequence I	0/0	0/0	0/0	0/0	0/0
Sequence II	0/0	10/0	110/0	0/0	80/0
Sequence III	0/0	0/0	0/0	0/0	0/0
Copper Corrosion					
3 hr, @ 100°C	ND	1A	1A	3A	1B
Water by Karl Fischer, wt%	0.11	0.085	0.041	0.135	0.21
TFOUT, Ox Induction, min	121	107	155	243	222

TABLE 6. Lubricant Analyses, SAE 30, SF/CC Oils

AL Number	15789	15792	15800	15803	15804	15808	15794	15795	15796
Viscosity Grade	30	30	30	30	30	30	30	30	30
Service Classification	SF/SE/CC	SF/CC	SF/CC	SF/SE/CC	SF/CC	SF/SE/CC	SF/CC	SF/SE/CC	SF/SE/CC
Kinematic Viscosity, cSt									
at 100°C	11.88	11.77	10.78	10.05	12.28	10.84	11.35	10.89	11.33
at 40°C	108.53	103.04	92.25	79.5	115.22	95.2	101.27	95.64	99.67
Viscosity Index	98	102	100	107	97	98	98	98	100
Apparent Viscosity, cP at -20°C	ND	ND	ND	ND	ND	ND	ND	ND	ND
Borderline Pumping Temperature, °C	ND	ND	ND	ND	ND	ND	ND	ND	ND
Flash Point, °C	233	222	229	216	246	221	229	234	236
Pour Point, °C	-31	-19	-16	-34	-13	-25	-26	-26	-24
Total Base Number, D 2896	5.8	6.3	6.7	5.6	5.8	6.2	6.4	6.7	6.1
Sulfated Ash, wt%	0.51	0.88	0.61	0.69	0.57	0.8	0.78	0.8	0.77
Carbon Residue, wt%	0.88	1.11	0.89	0.83	0.78	1	0.88	0.85	0.88
Elemental Content, %									
Sulfur	0.34	0.63	0.49	0.38	0.48	0.36	0.30	0.40	0.49
Nitrogen	0.059	0.033	0.052	0.043	0.053	0.041	0.043	0.046	0.045
Calcium	<0.01	0.11	<0.01	0.09	<0.01	0.06	0.05	0.07	0.06
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.10	0.14	0.09	0.10	0.09	0.11	0.10	0.10	0.10
Phosphorous	0.10	0.18	0.11	0.14	0.09	0.11	0.08	0.10	0.11
Elemental Content, ppm									
Copper	62	<10	80	<10	61	<10	<10	<10	<10
Boron	96	1	142	25	130	3	<1	<1	<1
Zinc	1020	1740	1064	1013	972	1164	1070	1060	1062
Phosphorous	871	1509	921	1017	829	990	949	945	945
Barium	4	<1	1	12	<1	1	<1	6	3
Magnesium	855	414	1131	350	1058	416	393	403	383
Sodium	11	4	1	25	1	680	780	545	710
Foam/Foam-Stability, mL									
Sequence I	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Sequence II	0/0	0/0	0/0	0/0	0/0	130/0	25/0	20/0	35/0
Sequence III	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Copper Corrosion 3 hr, @ 100°C	1A	1A	1A	1A	1A	3A	1A	1B	3A
Water by Karl Fischer, wt%	0.138	0.113	0.11	0.152	0.096	0.13	0.027	0.043	0.115
TFOUT, Ox Induction, min	108	219	134	124	105	127	134	156	127

ND = Not determined.

TABLE 7. Lubricant Analyses, Miscellaneous SF Oils and SA Oil

AL Number	15787	15788	15770	15798	15799	15802	15713
Viscosity Grade	15W-40	5W-30	10W-30	10W-30	30	30	30
Service Classification	SF/CC/CD	SF/SE/CC	SF/SE	SF/CD	SF/CE	SF/CD	SA
Kinematic Viscosity, cSt							
at 100°C	15.19	12.17	7.12	9.76	11.13	11.96	10.05
at 40°C	112.05	78.42	46.83	63.66	88.2	109.87	78.64
Viscosity Index	141	152	111	136	113	980	108
Apparent Viscosity, cP at -20°C	2750 @ -15°C	4900 @ -25°C	2750	3025	ND	ND	5700 @ -5°C
Borderline Pumping Temperature, °C	-26.9	-29.7	-33.2	-32	ND	ND	-15.8
Flash Point, °C	218	209	207	209	232	228	232
Pour Point, °C	-29	-34	-37.1	-31	-18	-17	-20.6
Total Base Number, D 2896	8.7	6.8	6.5	6.8	7.2	6.6	0.6
Sulfated Ash, wt%	0.86	0.89	0.84	0.91	0.96	0.78	0.13
Carbon Residue, wt%	1.02	0.96	1.13	1	1.05	0.89	0.23
Elemental Content, wt%							
Sulfur	0.41	0.33	0.39	0.50	0.44	0.44	2.12
Nitrogen	0.066	0.042	0.026	0.036	0.038	0.054	0.043
Calcium	<0.01	0.11	0.20	0.12	0.13	0.05	<0.01
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.13	0.12	0.02	0.11	0.12	0.10	<0.01
Phosphorous	0.13	0.13	0.04	0.13	0.14	0.11	<0.01
Elemental Content, ppm							
Copper	<10	25	<10	<10	<10	<10	<10
Boron	47	<1	26	<1	1	<1	<1
Zinc	1103	1079	278	1230	1303	1189	6
Phosphorous	973	964	296	1111	1191	1009	10
Barium	5	1	136	<1	<1	<1	<1
Magnesium	1152	246	237	428	527	388	<1
Sodium	0	274	20	44	9	750	3
Foam/Foam-Stability, mL							
Sequence I	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Sequence II	80/0	60/0	10/0	155/0	0/0	0/0	70/0
Sequence III	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Copper Corrosion 3 hr, @ 100°C	1B	1B	ND	4B	3A	1A	ND
Water by Karl Fischer, wt%	0.156	0.114	0.05	0.194	0.16	0.115	0.1
TFOUT, Ox Induction, min	132	175	24	135	155	94	<5

ND = Not determined.

TABLE 8. Summarized Properties, 10W-30, SF/CC Oils

	Minimum	Maximum	Average	Standard Deviation
Kinematic Viscosity, 100°C, cSt	9.58	11.92	10.55	0.53
Viscosity Index	122	160	137	11
Apparent Viscosity, cp, -20°C	2750	3950	3278	318
Flash Point, °C	204	235	217	10
Total Base No., D 2896	0.8	6.9	5.5	1.2
Sulfated Ash, wt%	0.60	1.04	0.79	0.10
Elements				
Zinc, ppm	757	1459	993	195
Phosphorous, ppm	736	1323	917	157
Sulfur, wt%	0.25	0.86	0.46	0.17
Nitrogen, wt%	0.022	0.055	0.043	0.007
TFOUT, minutes	92	254	148	43

TABLE 9. Summarized Properties, SAE30, SF/CC Oils

	Minimum	Maximum	Average	Standard Deviation
Kinematic Viscosity, 100°C, cSt	10.05	12.28	11.24	0.68
Viscosity Index	97	107	100	3
Flash Point, °C	216	246	230	9
Total Base No., D 2896	5.6	6.7	6.2	0.4
Sulfated Ash, wt%	0.51	0.88	0.71	0.12
Elements				
Zinc, ppm	972	1740	1129	235
Phosphorous, ppm	829	1509	997	200
Sulfur, wt%	0.30	0.63	0.43	0.10
Nitrogen, wt%	0.033	0.059	0.046	0.008
TFOUT, minutes	105	219	137	34

TABLE 10. Distribution of Additive Package Types

Additive Package Elements*	Number of Oils					
	SF/CC 10W-30	SF/CC SAE 30	SF/CD SAE 30	SF/CD 15W-40	SF/CD 10W-30	SF 10W-30
Mg, Cu, B	10	3	0	0	0	0
Mg, Ca, Na	8	4	1	0	1	0
Mg, B	2	0	0	1	0	0
Mg, Ca, B	1	0	0	0	0	0
Mg, Ca, Cu, B	1	0	0	0	0	0
Mg, Ca, Na, Ba, Cu, B	1	0	0	0	0	0
Ca, Cu	1	0	0	0	0	0
Ca	1	0	0	0	0	0
Ca, Mg	0	1	1	0	0	0
Ca, Mg, Na, B	0	1	0	0	0	0
Ca, Ba, Mg, Na, B	0	0	0	0	0	1

*Note:all oils contained Zn and P.

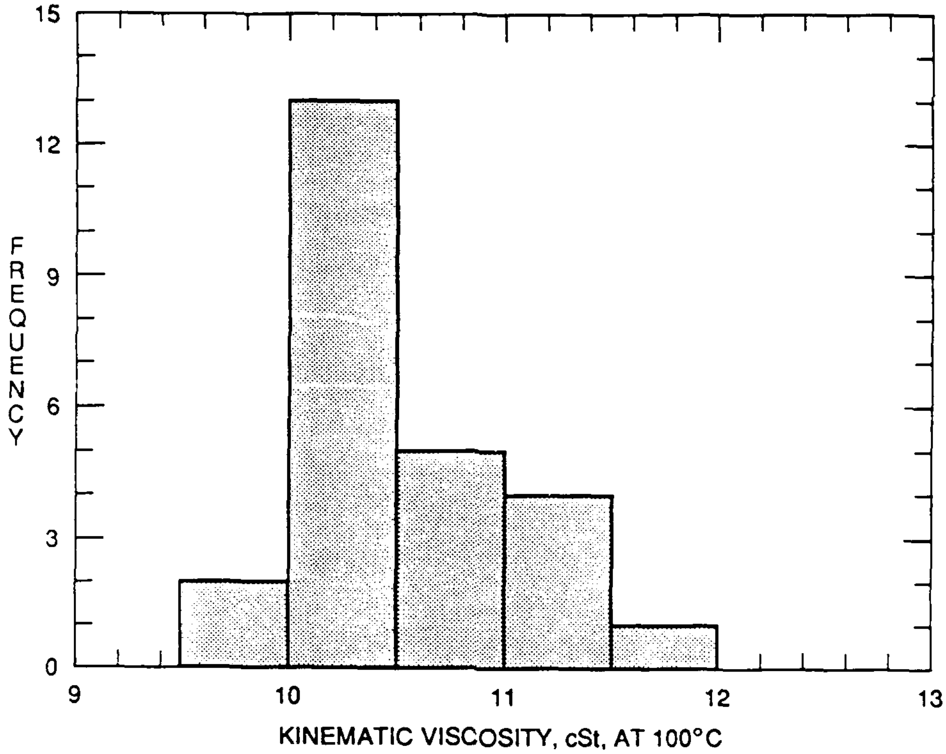

Figure 1. Kinematic viscosity at 100°C, cSt for SF/CC 10W-30 oils

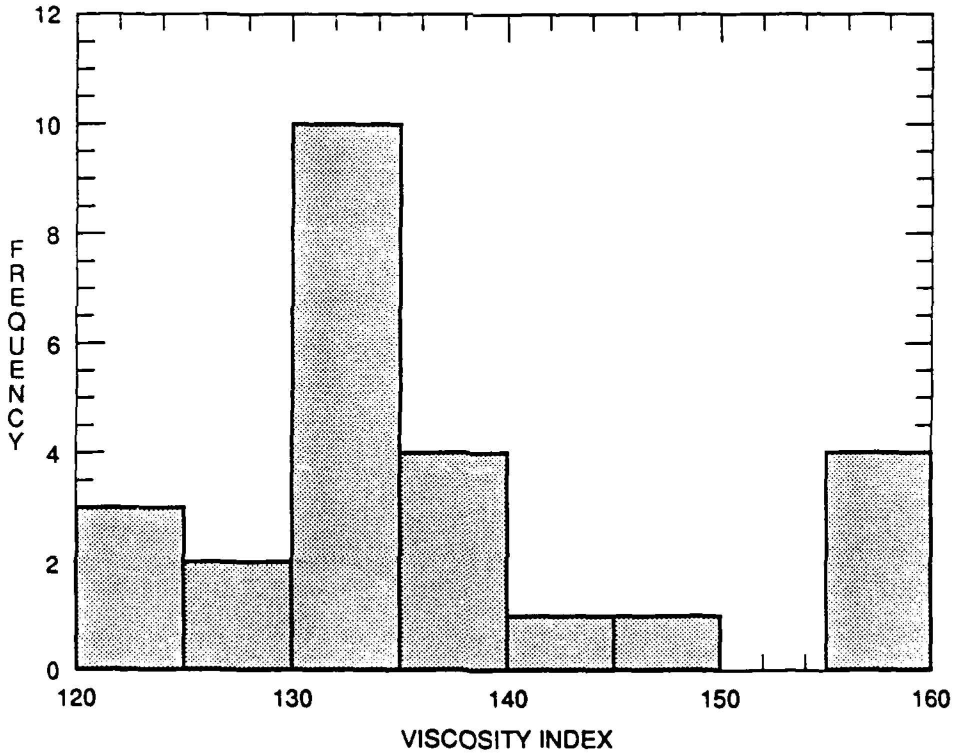

Figure 2. Viscosity index for SF/CC 10W-30 oils

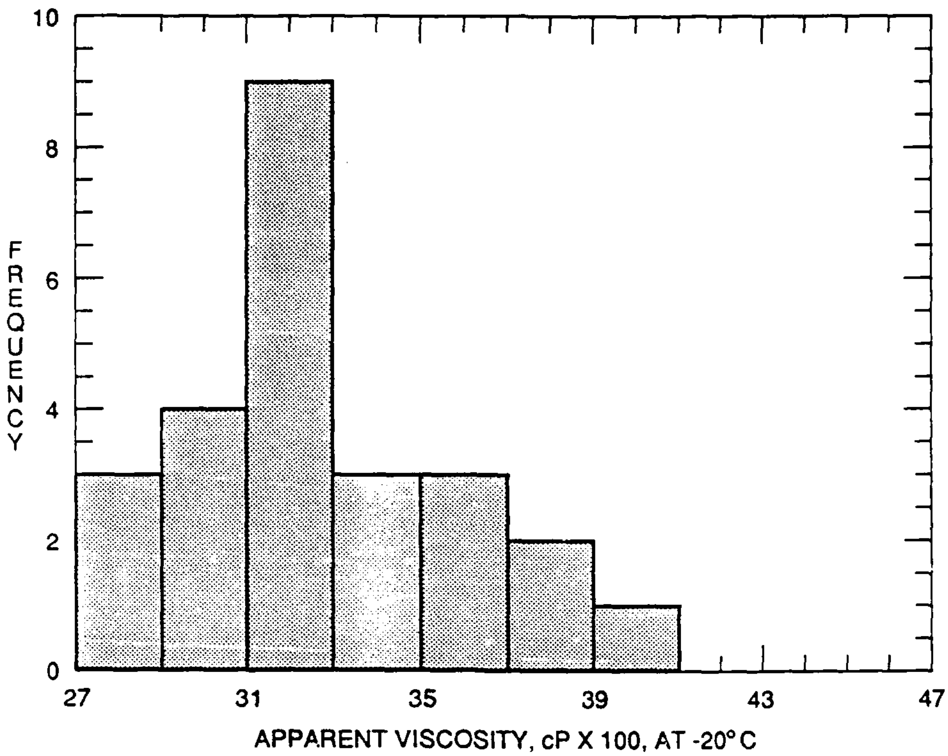

Figure 3. **Apparent viscosity, cP @ -20°C for SF/CC 10W-30 oils**

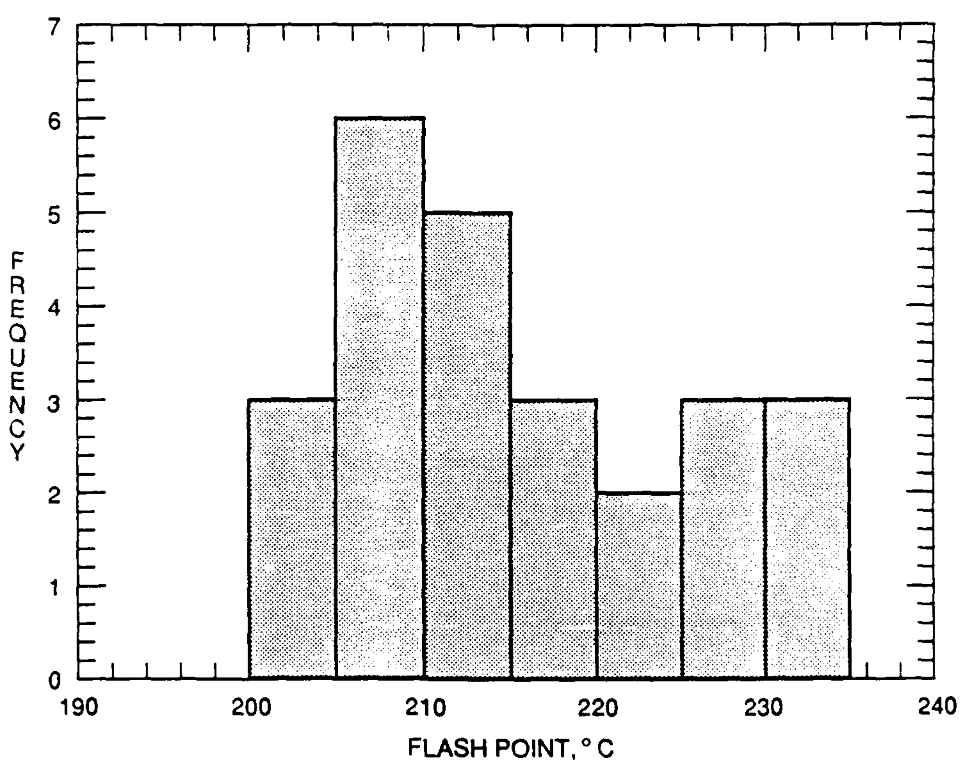

Figure 4. **Flash point, °C for SF/CC 10W-30 oils**

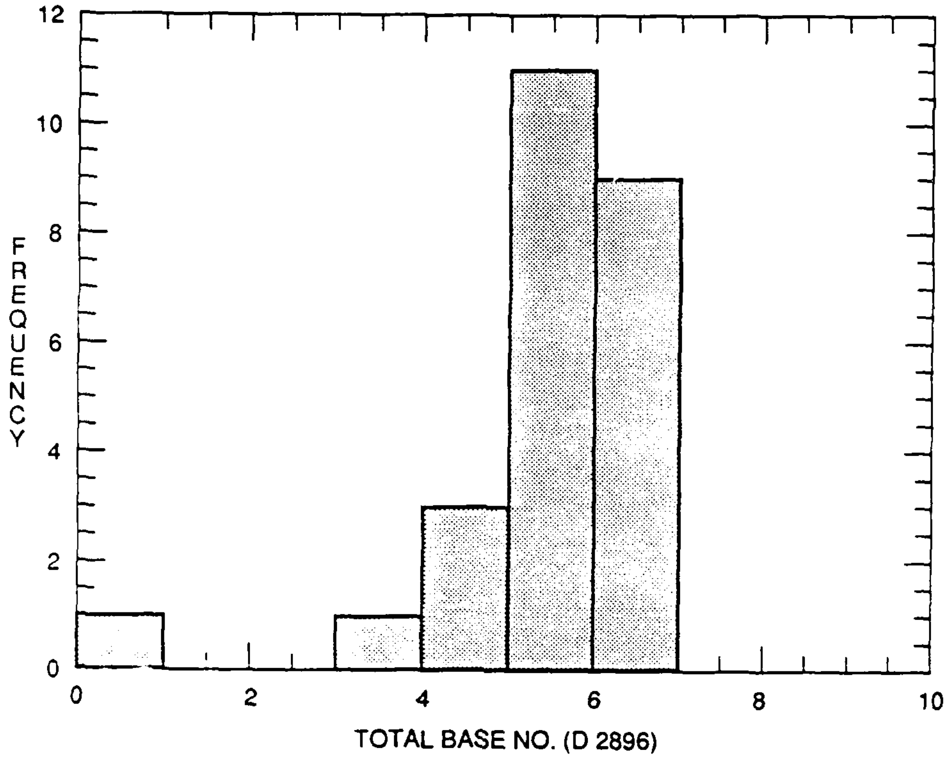

Figure 5. Total base No. D 2896 for SF/CC 10W-30 oils

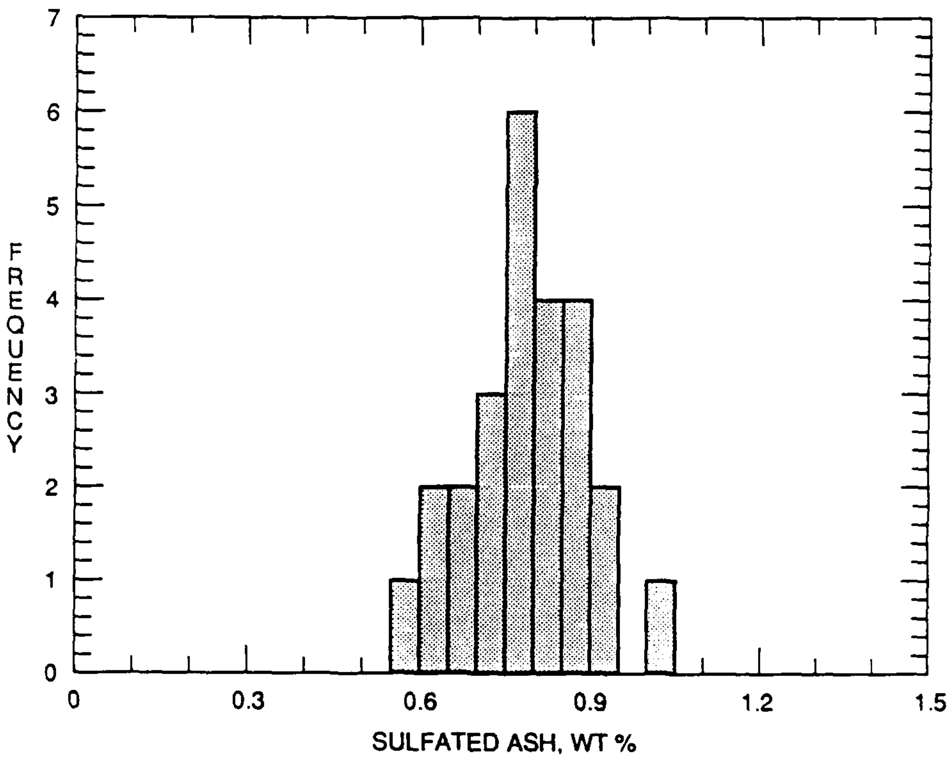

Figure 6. Sulfated ash for SF/CC 10W-30 oils

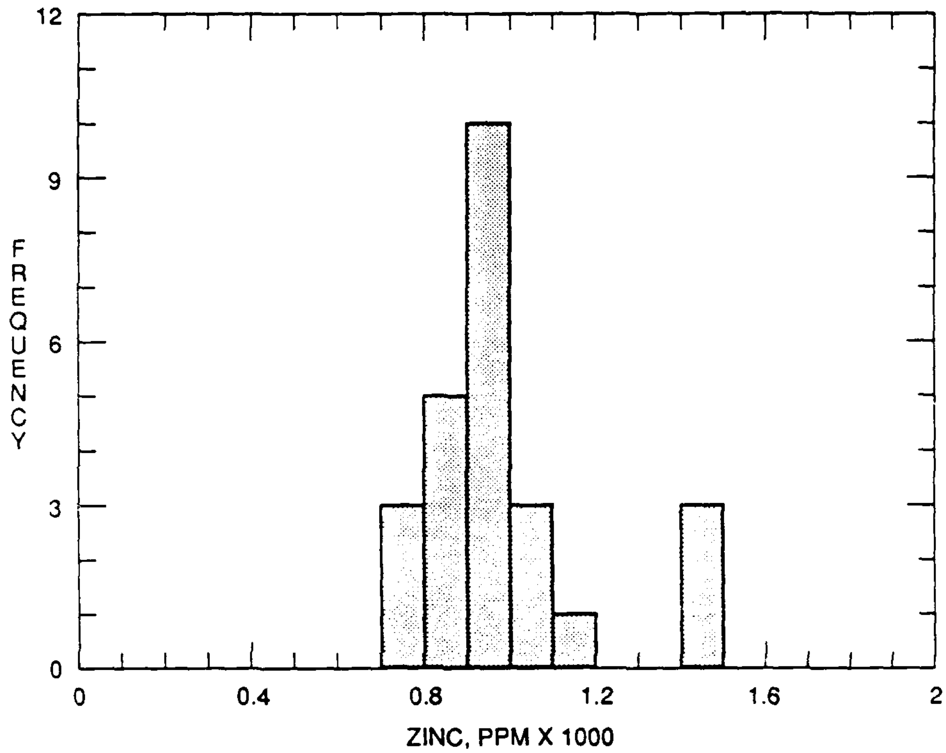

Figure 7. Zinc content for SF/CC 10W-30 oils

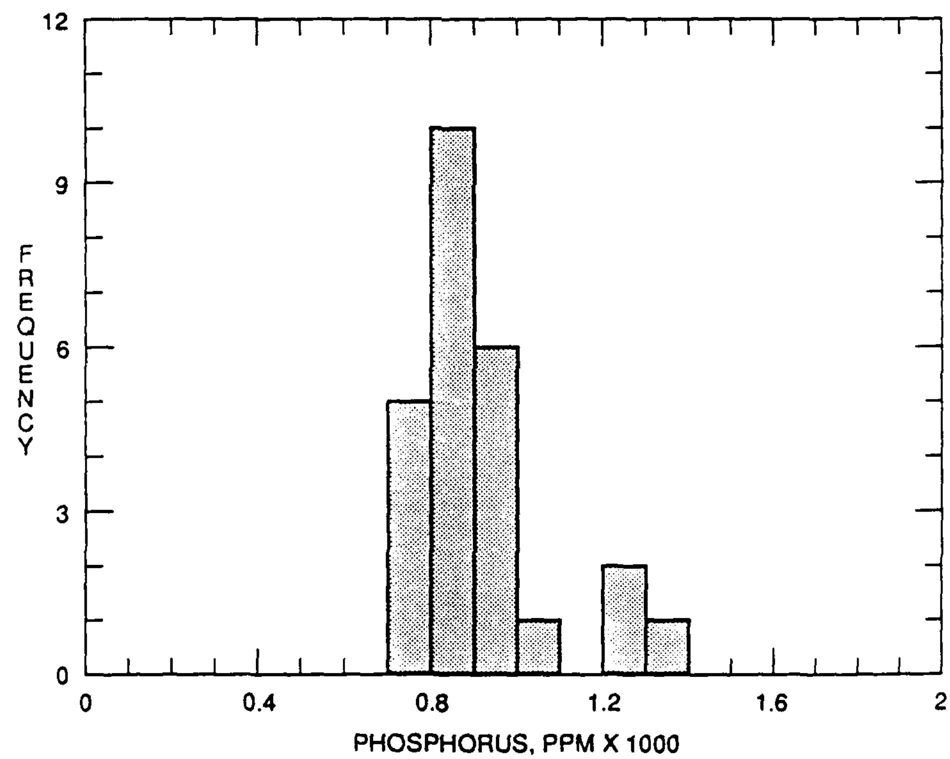

Figure 8. Phosphorous content for SF/CC 10W-30 oils

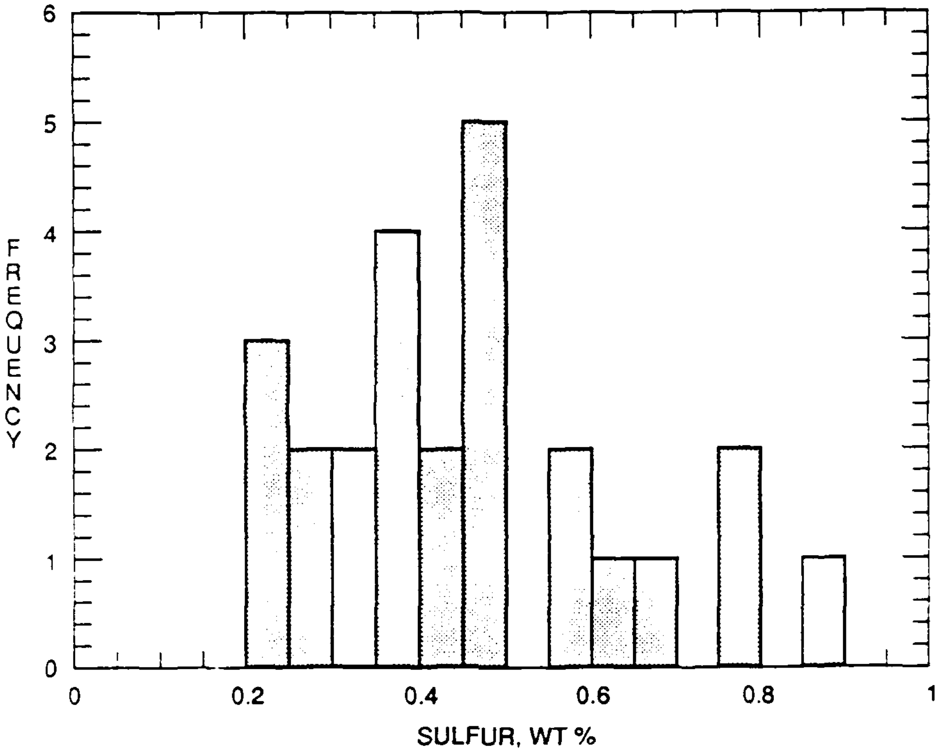

Figure 9. Sulfur content for SF/CC 10W-30 oils

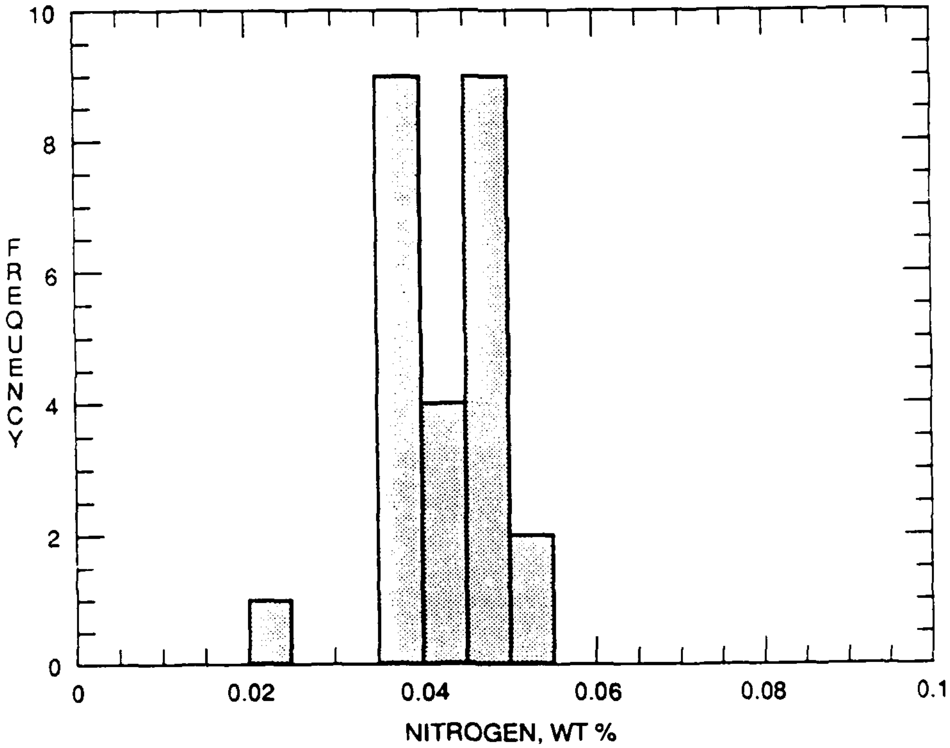

Figure 10. Nitrogen content for SF/CC 10W-30 oils

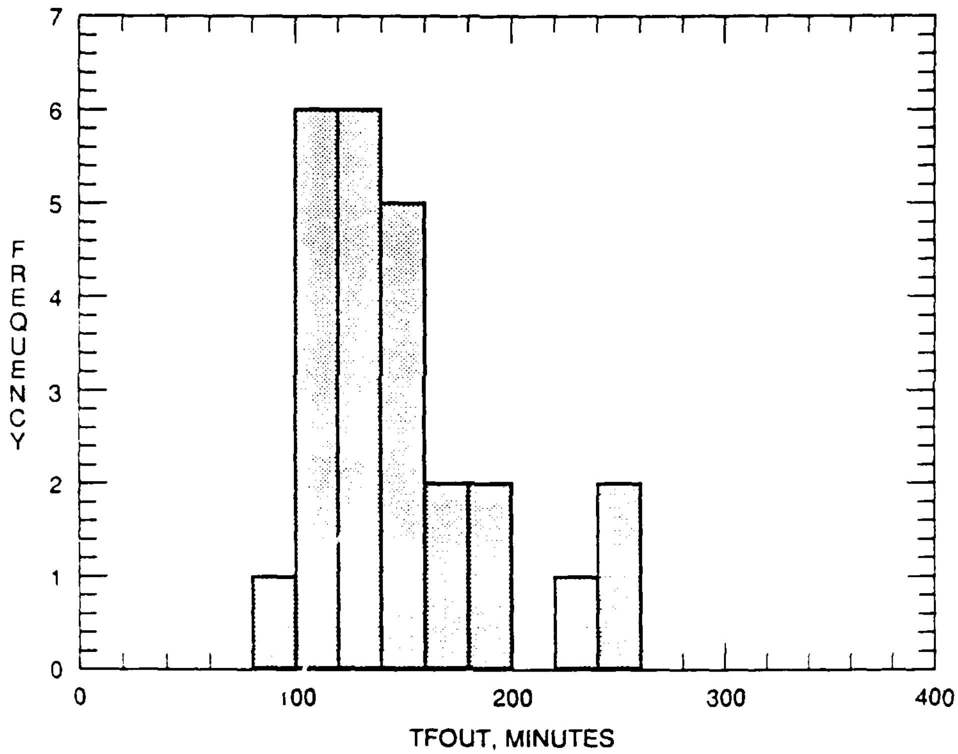

Figure 11. TFOUT minutes for SF/CC 10W-30 oils

Figs. 12 through 21 show oil property frequency distributions for the SAE 30 grade oils labeled SF/CC. Once again, the most frequently occurring property ranges were compiled to determine the properties of a "composite" SAE 30 grade oil as shown below:

Property	Range
Kinematic Viscosity, 100°C, cSt	10.5-11.0
Viscosity Index	95-100
Sulfated Ash, wt%	0.7-0.8
Flash Point, °C	220-230
Total Base No. (D 2896)	6.0-6.5
Zinc, ppm	1000-1100
Phosphorous, ppm	900-1000
Sulfur, wt%	0.30-0.40
Nitrogen, wt%	0.040-0.045
TFOUT, minutes	120-140

One sample of the given brand/label 10W-30 oil was obtained in both the Washington D.C. and San Antonio, TX areas for four different companies. Properties of the samples were compared to determine if the same composition oil was being sold in two different geographic areas. Samples AL-15717 and AL-15791 were purchased from the same auto

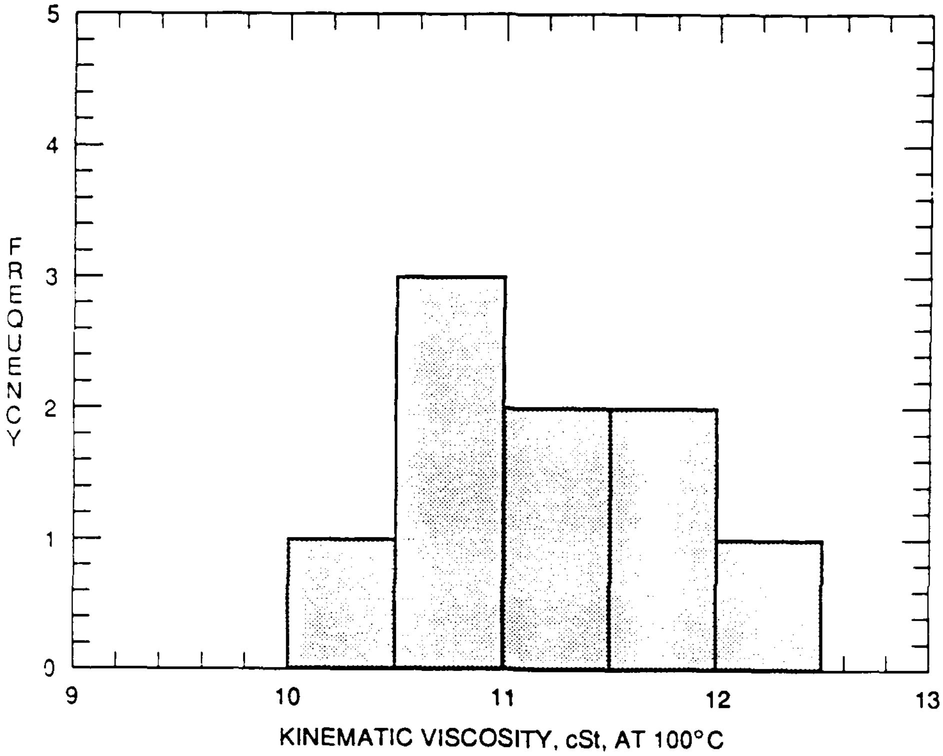

Figure 12. Kinematic viscosity at 100°C, cSt for SF/CC SAE 30 oils

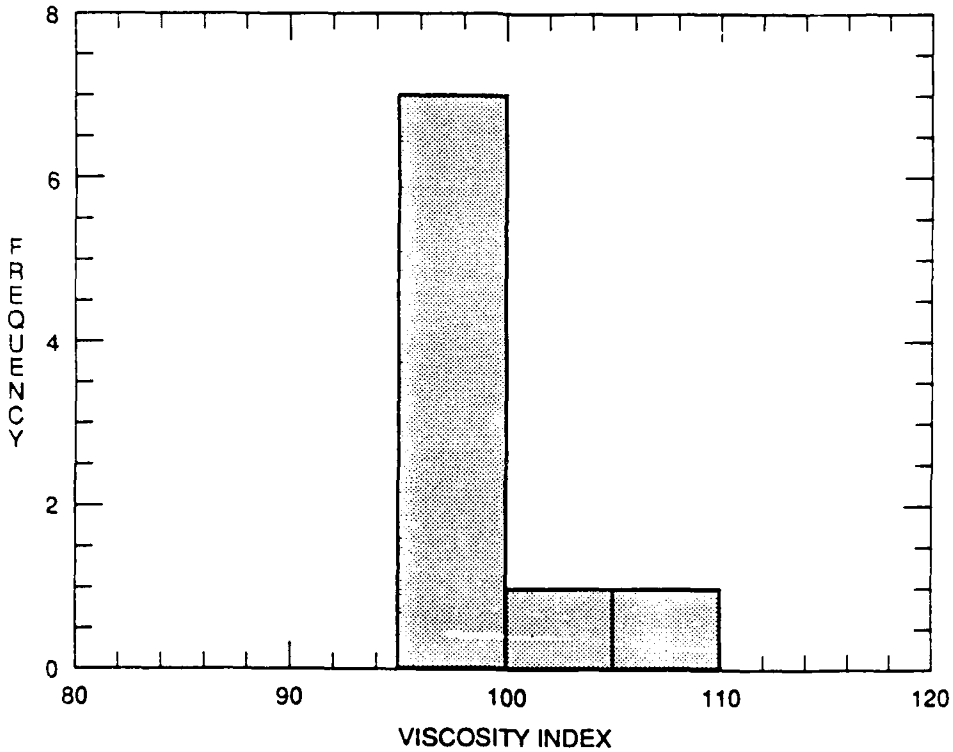

Figure 13. Viscosity index for SF/CC SAE 30 oils

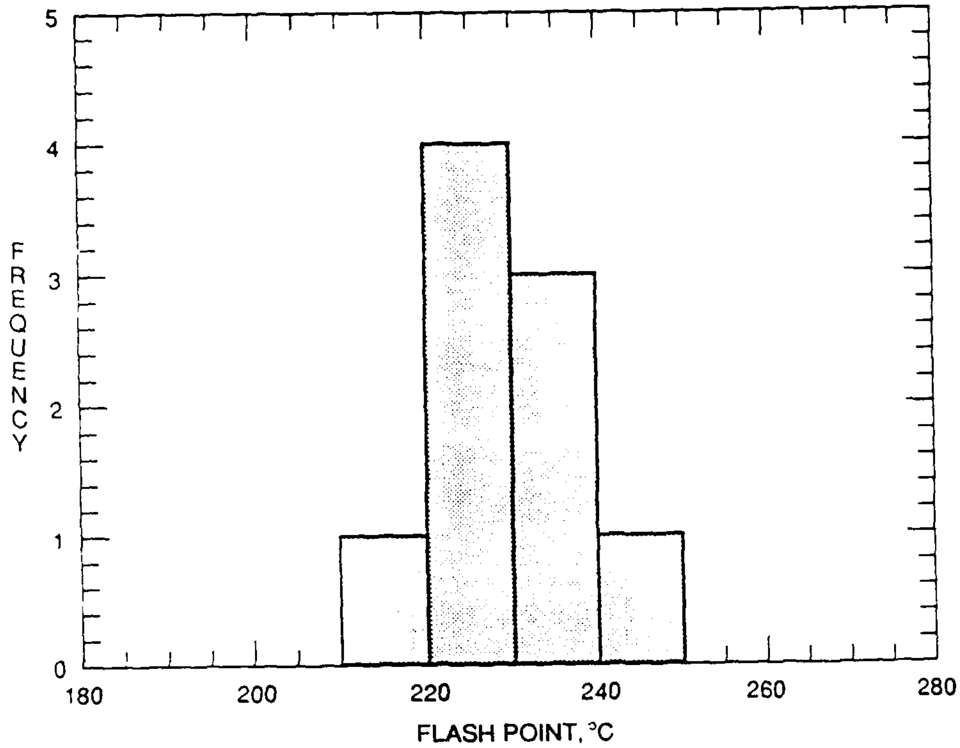

Figure 14. Flash point, °C for SF/CC SAE 30 oils

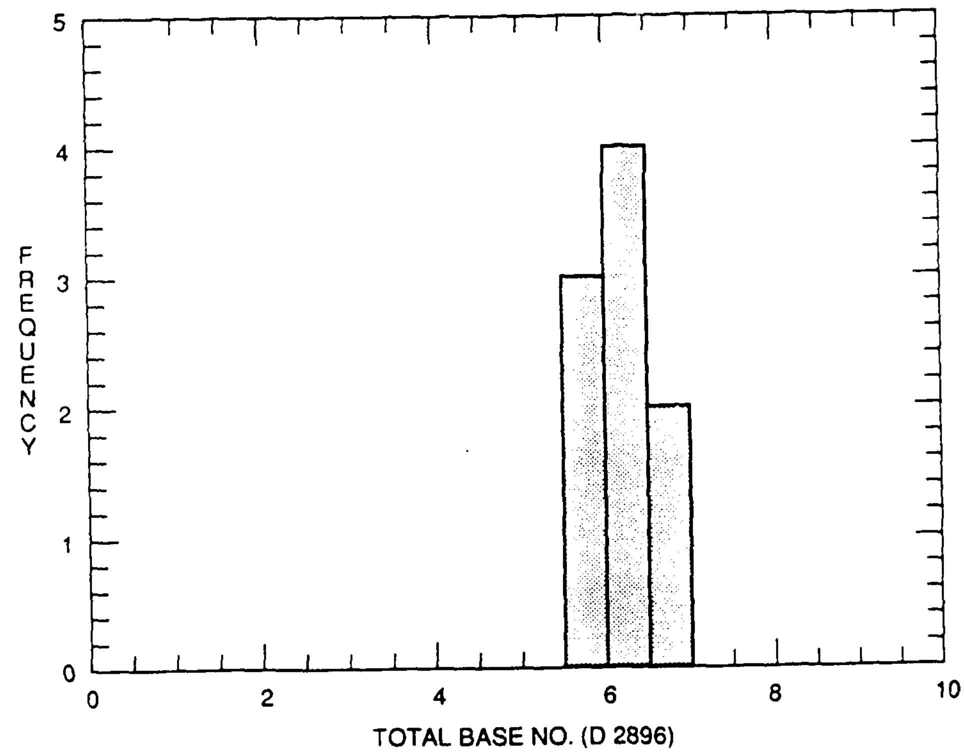

Figure 15. Total base No. D 2896 for SF/CC SAE 30 oils

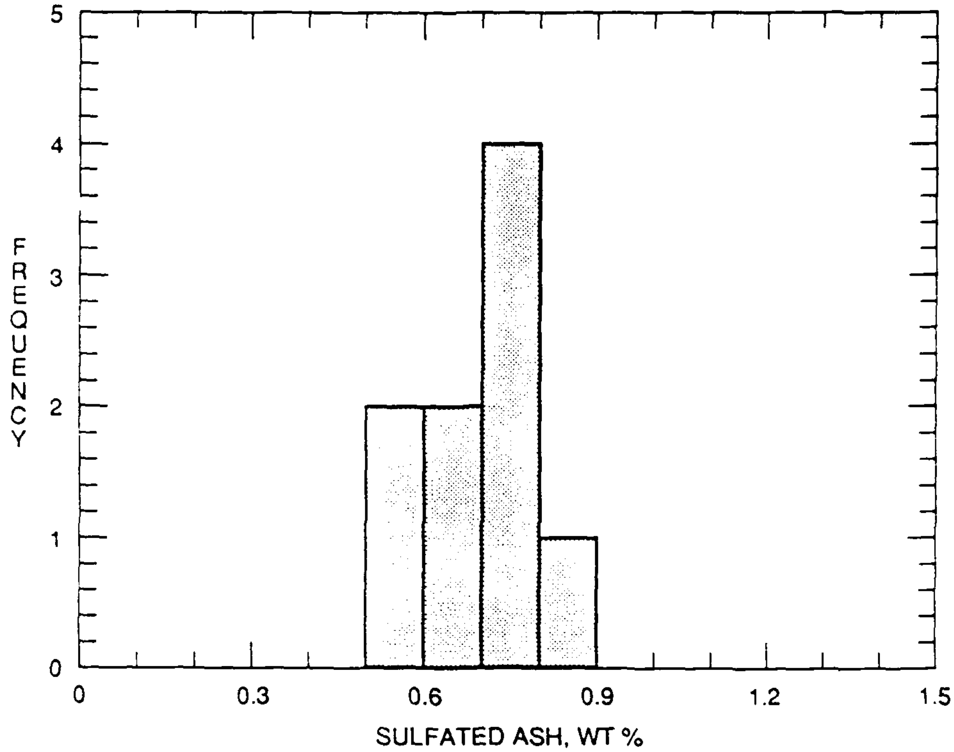

Figure 16. Sulfated ash for SF/CC SAE 30 oils

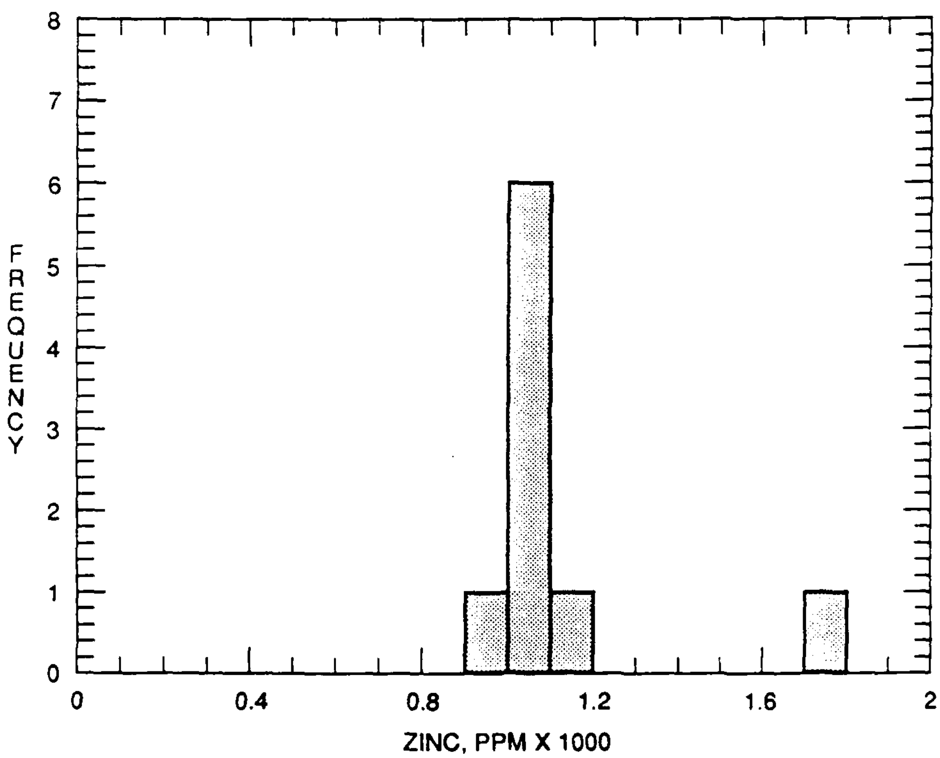

Figure 17. Zinc content for SF/CC SAE 30 oils

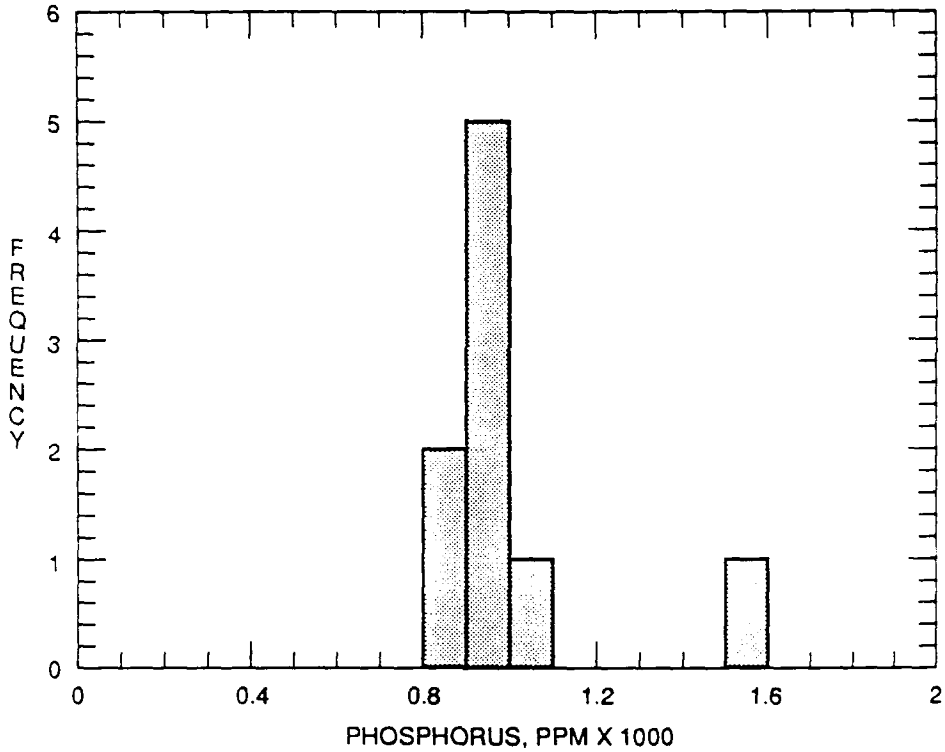

Figure 18. Phosphorous content for SF/CC SAE 30 oils

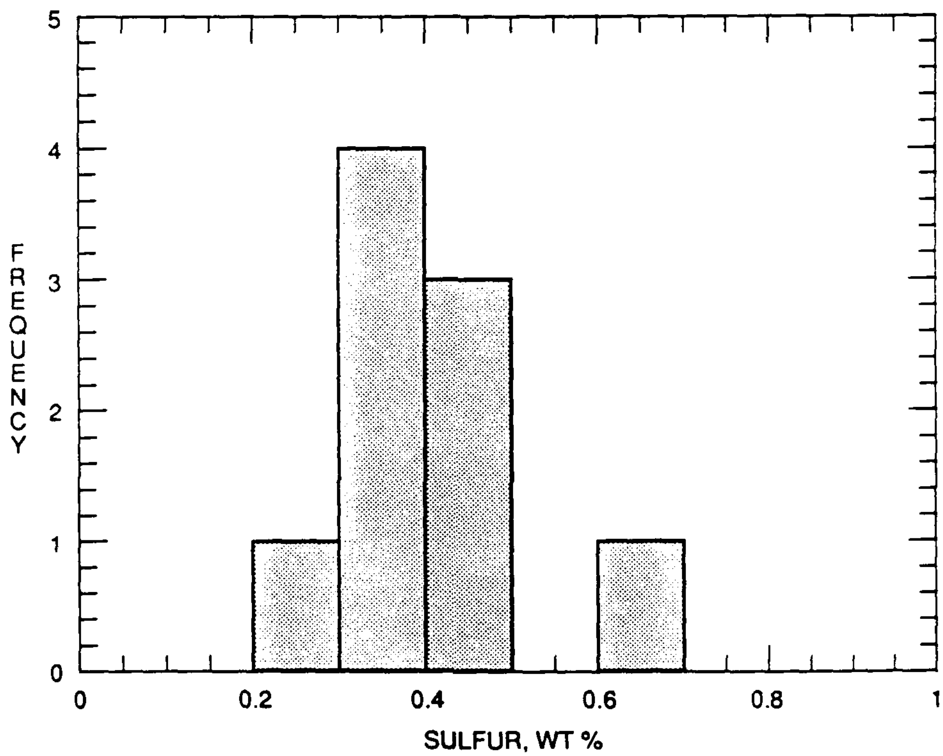

Figure 19. Sulfur content for SF/CC SAE 30 oils

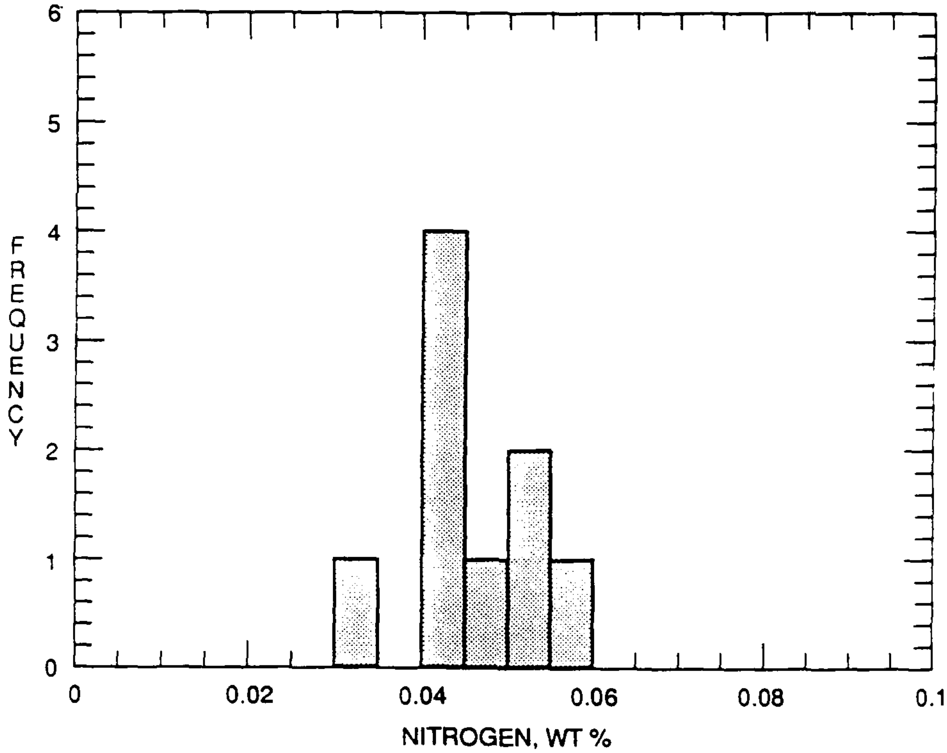

Figure 20. Nitrogen content for SF/CC SAE 30 oils

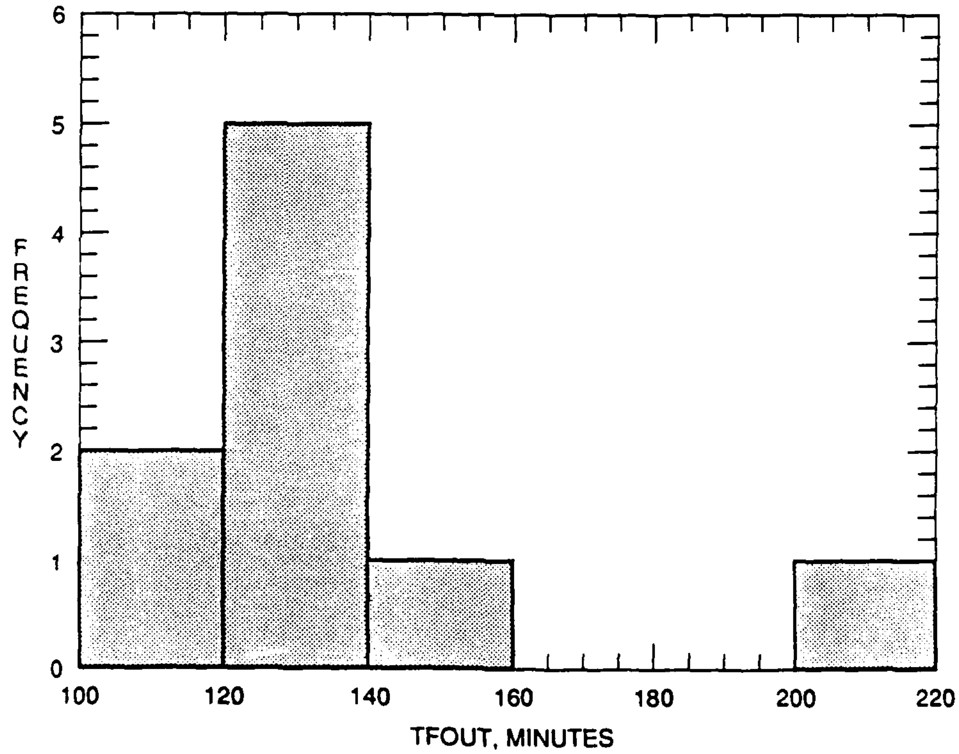

Figure 21. TFOUT minutes for SF/CC SAE 30 oils

parts chain (source A). Although the oils had similar additive chemistries, they had somewhat different physical/chemical properties such as flash point, sulfur content, sulfated ash, and total base number. Two samples were obtained from another auto parts chain (source B). Oils AL-15729 and AL-15807 differed substantially in viscosity index, flash point, sulfur, and sodium content, while the additive packages were of the same chemistry type. Oils from source A were similar and possibly within blending tolerances but were not exact duplicates. The same conclusion was made for the oils from source B. Two samples were obtained from a mass merchandiser (source C). Oils AL-15727 and AL-15793 had major differences in boron, calcium, and sodium contents and had minor differences in viscosity index, flash point, and sulfated ash. Oils AL-15728 and AL-15786 were from another mass merchandiser (source D). These oils differed in additive packages as their calcium, copper, boron, and sodium contents were quite different. Based on additive contents, the two oils from source C were of different composition as were the two samples from source D.

During late 1986 and early 1987 when the oil samples were procured for this data base, oil specification MIL-L-46152B was in effect. Specification MIL-L-46152C became effective 27 August 1987 and included some minor changes in pour point requirements (less restrictive) for grades 10W and 10W-30, the deletion of grade 5W-20 and addition of grade 5W-30, and the revision of several analytical test methods. Specification MIL-L-46152D became effective 1 August 1988 and retained the same finished oil property requirements as the previous revision; however, engine test procedures and requirements were updated. From the standpoint of physical properties, the oils obtained for this data base in 1986 through 1987 should still meet the finished oil property requirements of the latest specification revision. TABLE 11 shows a listing of oils that had one or more properties outside the requirements of MIL-L-46152D. Twenty-three different samples (57.5 percent) failed one or more of the physical/chemical property tests with seven (17.5 percent) of the failures being considered borderline. Sequence II, 5-minute foam limits (ASTM D 892) and cold cranking simulator apparent viscosity were the tests most frequently failed. It should be noted that all samples passed the 10-minute foam requirements with zero mL foam. Sample AL-15770 had a kinematic viscosity at 100°C, which was below the minimum for SAE 30 grade despite being labeled as a 10W-30 product. This oil also had unusually low zinc and phosphorous contents and performed poorly in the TFOUT. Oil AL-15788, which was labeled 5W-30, did not meet the low-temperature requirements for this viscosity grade. Sample AL-15804 failed the pour

TABLE 11. Lubricants With Properties Outside MIL-L-46152D Requirements

Property	Oil ID	Grade	Property Value	Property Limit	Comment
Kinematic Viscosity, 100°C	AL-15770	10W-30	7.12	9.3 min	
Apparent Viscosity at -20°C, cP	AL-15716	10W-30	3700,3800	3500 max	
	AL-15720	10W-30	3700,3750	3500 max	
	AL-15726	10W-30	3600,3700	3500 max	
	AL-15727	10W-30	3850,4000	3500 max	
	AL-15772	10W-30	3600,3800	3500 max	
	AL-15793	10W-30	3600,3700	3500 max	
at -25°C, cP	AL-15788	5W-30	4900,5000	3500 max	
BPT, °C	AL-15788	5W-30	-29.7	-30 max	Borderline
Pour Point, °C	AL-15786	10W-30	-28	-30 max	Borderline
	AL-15800	30	-16	-18 max	Borderline
	AL-15802	30	-17	-18 max	Borderline
	AL-15804	30	-13	-18 max	
	AL-15788	5W-30	-34	-35 max	Borderline
Flash Point, °C	AL-15722	10W-30	204	205 min	Borderline
	AL-15790	10W-30	204	205 min	Borderline
	AL-15803	30	216	220 min	
P, wt%	AL-15790	10W-30	0.15,0.13	0.14 max	Borderline
	AL-15792	30	0.18,0.15	0.14 max	
Foam, D 892 Sequence II,				150 mL max	
5 minute	AL-15716	10W-30	180	150 mL max	
	AL-15724	10W-30	190	150 mL max	
	AL-15725	10W-30	320	150 mL max	
	AL-15726	10W-30	290	150 mL max	
	AL-15727	10W-30	285	150 mL max	
	AL-15728	10W-30	160	150 mL max	Borderline
	AL-15771	10W-30	220	150 mL max	
	AL-15797	10W-30	160	150 mL max	Borderline
	AL-15798	10W-30	155	150 mL max	Borderline
	AL-15807	10W-30	190	150 mL max	

Note: All samples had 0 mL foam after 10 minutes settling time.

point requirement for SAE 30 grade by 5°C, and sample AL-15803 failed the minimum flash point by 4°C.

IV. CONCLUSIONS

Overall, 57.5 percent of the samples obtained failed one or more of the physical/chemical tests of MIL-L-46152. Although 17.5 percent of the failures were considered borderline, 40 percent clearly failed at least one of the tests. Foam test and cold cranking simulator apparent viscosity were the requirements most frequently failed. Based on the number of samples that failed property tests, it is not advisable for the U.S. Army to procure commercially available oils for administrative service at this time.

V. RECOMMENDATIONS

Some of the commercially available administrative type service engine oils do not appear to have consistently high quality. It is recommended that the U.S. Army continue to monitor the results of the SAE oil labeling assessment program to determine when it will be feasible to obtain commercially available administrative service oils of consistent high quality. It is also recommended that the Army conduct a brief follow-on survey and sample analysis of the latest generation oils that meet API service classification SG.

VI. LIST OF REFERENCES

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PM BFVS, ATTN: AMCPM-BFVS 1
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P O BOX 4005
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FORT KNOX KY 40121

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US ARMY QUARTERMASTER SCHOOL
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ATSM-LL FSD 1
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DIRECTOR
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(AVSCOM)
PROPULSION DIRECTORATE
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21000 BROOKPARK ROAD
CLEVELAND OH 44135-3127

PROJECT MANAGER
PETROLEUM & WATER LOGISTICS
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4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

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DEVELOPMENT ACTIVITY
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DEPARTMENT OF THE NAVY

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PENSACOLA FL 32508-5300

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200 STOVAL ST
ALEXANDRIA VA 22322

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NAVY PETROLEUM OFFICE
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CAMERON STATION
ALEXANDRIA VA 22304-6180

CDR
NAVAL SEA SYSTEMS COMMAND
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WASHINGTON DC 20362-5101

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
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WASHINGTON DC 20380

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CG
USMC RDA COMMAND
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DEPARTMENT OF THE AIR FORCE

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CDR
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OTHER GOVERNMENT AGENCIES

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